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PROJECT INITIATION

Date: Feb. 20, 1969

Project Title: Airborne Radiometric Survey of the Coastal Area of Georgia

Project No.: A-1147

Project Director: Mr. John E. Husted

Sponsor: Department of Mines, Mining & Geology, State of Georgia

Effective . . . February 5, 1969 . . . . Estimated to run until: June 30, 1969 . . . .

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PROJECT TERMINATION

Date ______________

PROJECT TITLE: Airborne Radiometric Survey of the Coastal Area of Georgia

PROJECT NO: A-1147

PROJECT DIRECTOR: C. C. Ostrander

SPONSOR: Department of Mines, Mining & Geology, State of Georgia

TERMINATION EFFECTIVE: June 30, 1969

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FINAL REPORT

PROJECT NO. A-1147

AIRBORNE RADIOMETRIC SURVEY

By

Charles C. Ostrander
Research Scientist

Performed for

THE GEORGIA DEPARTMENT OF MINES,
MINING AND GEOLOGY

FEBRUARY, 1970

Mineral Engineering Branch
Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

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Performed for
THE GEORGIA DEPARTMENT OF MINES,
MINING, AND GEOLOGY

MINERAL ENGINEERING BRANCH
ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

Purpose

Project A-1147 was funded by the Georgia Department of Mines, Mining and Geology to evaluate the capabilities of gamma ray (G.R.) spectrometry in airborne radiometric surveying to detect potentially commercial deposits of heavy minerals, and to produce an isorad map of a limited area of Southeast Georgia.

Instrumentation

G. R. spectrometry is a technique of measuring the energy of individual gamma rays which, in turn, are indicative of the gamma emitting element.

The methodology involves (1) a radiation detection device (e.g. a NaI crystal) which, when activated by a gamma ray, emits light with an intensity proportional to that of the energy of the incident gamma ray, (2) a photomultiplier tube which detects the intensity of this light and converts it into an electrical pulse, proportional to this intensity, (3) an amplifier for this pulse, and (4) an analyzer to determine the energy of the initiating gamma ray as indicated by the pulse height (amplitude).

The first 3 elements of the system are essentially the same in all scintillation counting systems. The analyzer is unique to G.R. spectrometry.

Two types of analyzers were used in this study, (1) single-channel and (2) multi-channel. A single-channel analyzer discriminates against pulses from the amplifier which are smaller than a pre-selected minimum (the baseline), or larger than a pre-selected maximum (baseline plus window width). The pulses with amplitudes between these two pre-selected values (the window) pass through the circuit to a rate meter, integrating circuit, or some other counting device. All other pulses are rejected.

A multi-channel analyzer divides the spectrum of radiation into a specific number of discrete windows (e.g. a 400 channel analyzer creates 400 separate windows). The width of the spectrum being analyzed and the energy boundaries of each window are controlled by the operator and are calibrated using known sources of radiation. When a pulse enters the analyzer it is measured and a trigger signal is sent to the channel which encompasses this energy level. The counting mechanism for this channel is advanced by 1, indicating that one more pulse of this energy level has passed through the system.

Upon completion of the analysis, the number contained in the counting device of each channel is displayed in some selected manner, such as a cathode ray tube (CRT), X-Y plotter, punch tape, or on a typewriter. The CRT or X-Y plotter would display the information as a graph with the X axis representing the channel number (or energy level) and the Y axis, the number of pulses contained in that channel.

Both systems have situations to which they are best suited. The multi-channel system requires a stationary detector, e.g. truck, laboratory, or helicopter mounted so that the detector can be maintained in a relatively stable position during the time of the analysis. The single channel system can be used with a moving detector. The reliability of a single channel recording is a function of the speed of the detector and the intensity of radiation being received. Thus, low intensity radiation requires a slowly moving detector while an area of high intensity can be reliably recorded at faster rates. The single channel analyzer is connected to a rate meter and the recorder for truck or airborne monitoring of the areal distribution of radiation intensity.

To increase the validity of results in the present work, the crystal was shielded from the upper atmospheric radiation by a hemi-cylindrical lead shield 2 inches thick. For gamma ray energies of the range measured in this study (See below), this 2 inches of lead shielding effectively reduces the radiation from above to 1/256 of its true value, since the half value thickness (the half value thickness of a material is that thickness which reduces the radiation intensity to one half of its initial value) of lead for this energy range is approximately 1/4 inch. With this arrangement, an anomaly would almost certainly be a result of ground radiation rather than spurious atmospheric radiation caused by sunspot activity, etc.

Procedure

The initial program was to:

(1) Establish the optimum radiation window (single channel) for the detection of uranium and thorium (associated with potentially economic minerals);

(2) Establish the optimum elevation and speed to be used in airborne work;

(3) Define an area and, using a single channel analyzer,

(a) Fly the area using a one mile traverse spacing,

(b) Drive the same area covering all available unpaved roads,

In both cases the same radiation window (as found in (1) above) to be used;

(4) Take auger samples at locations selected within the defined area (the locations would be chosen both randomly and at observed anomalies);

(5) Analyze, using the multi-channel analyzer, as many surface sample locations as possible);

(6) Analyze the samples for heavy mineral content and, in some cases, TiO_2;

(7) Analyze the results mathematically to find significant correlations in the data;

(8) Present an isorad map of the airborne data;

(9) Draw conclusions on the value of G.R. spectrometry toward the exploration for heavy mineral deposits;

(10) Establish a basis for cost estimates for recommended studies in the future.

Two aircraft were used in this study. A Cherokee 6, a low wing plane was most suited for mounting the instruments. The low wing, however, made low level navigation very difficult. The Helio Courier of the Georgia Forestry Commission was best for navigation, but was awkward for mounting the instruments. The Cherokee was more stable but higher speeds were required. The navigational advantage of the Helio Courier was the deciding factor, with the additional factor of its under 100 mph speed stability.

The navigation along the traverses was maintained as close as possible under the varying conditions. The instrument operator had the responsibility of marking known points on the map and time marking the recorded signal. With these known points and the assumption of straight line navigation at constant ground speed between these points, a reasonable estimate of geographic position of an anomaly could be made. Eight such traverses were run from the western boundary toward the east. Most of the traverses were rerun, some several times, from west to east and from east to west to check repeatability and speed-time constant effects.

Results and Discussion

1) The data from one single channel analyzer was recorded with a second, non-recording channel available for visual observation. The radiation

window chosen for this study accepted gamma rays from .22 MEV to .65 MEV. This window fit within the sensitivity framework of the instrumentation and included the major thorium photopeaks at .23 MEV and .58 MEV and the uranium photopeak at .61 MEV. With a larger crystal the higher energy radiation peaks of uranium and thorium would be the target peaks.

2) The repeatability of the truckborne radiation was within the range of ±10%. The airborne repeatability was generally good, but navigation problems, e.g. crosswinds, prevented exact reruns of traverses.

The problem of optimum elevation would be simple were it not for safety, stability, and navigational problems. The lower the aircraft the higher the counting rate from the ground directly below the detection device. As the elevation increases, the attenuation of the radiation increases. If the traverse is flown at an elevation of, say 500 feet, and the pilot can hold his elevation to ±50 feet, the system, flying over a homogeneous surface, will detect in the range of 25% more radiation when the altitude dips to 450 feet than it will at 550 feet. Fluctuations in the ground surface have the same effect, so that flying over a river channel, e.g., will yield a lower counting rate than the surrounding area, assuming it is still a radioactively homogeneous surface.

If the altitude is raised significantly above 500 feet, e.g., 1,000 feet or more, the changes caused by altitude fluctuations and topographic anomalies is reduced, (a change from 950 to 1050 feet reduces radiation by about 15%) but attenuation in air has reduced the counting rate significantly (to about 1/3 of its value at 500 feet), and the resolution of the source area on the ground has been sharply reduced. An additional factor related to elevation is the variation in the vertical motion of the air. If flying is done at 200-250 feet above ground level, the flying conditions deteriorate rapidly after the sun has been up for 2 hours or so. At 500 feet, conditions are acceptable, as a rule, for 4 or more hours. This is a result of the uneven heating of the earth's surface which creates local updrafts. This condition is accentuated as the day progresses. However, the quiet conditions of early morning are the worst for accurate counting rates, because the radioactive gas, radon, which has accumulated in the still night air, has not yet been dispersed by the updrafts.

The speed of the aircraft is not as markedly significant to the counting rate as the factors cited above. The chief problem with speed is its control. The pilot's control of the speed is the airspeed indicator. He is far too busy flying safely at low altitudes to keep constant track of ground speed by using navigation points. A 20 mph tail-wind or head-wind or worse yet, a varying crosswind, can make ground speed control an impossible task without navigational aids and ground control, both of which increase the cost significantly.

Essentially, the speed of the aircraft, in conjunction with the time constant (an electrical "averaging" device which essentially means that any pulse that has entered the system during the last time constant, e.g., 2 seconds, is having a significant effect on the current reading of the rate meter) control the sharpness of the boundaries of anomalous radioactive bodies and the apparent geographic location of them. At high speeds and/or a long time constant, a geographically small body can essentially "disappear". At high speeds a small, sharp anomaly can be displaced by several hundreds of feet because of the time constant effect on the recorded signal.

For purposes of this study an elevation of 500 feet and a speed of 90 mph was selected. A time constant of 2 seconds was used.

3) The area chosen to be mapped was a rectangle measuring approximately 25 miles (E-W) by 8 miles (N-S) with its southern boundary approximately 4.75 miles north of the center of Folkston, Georgia, its eastern border, U. S. Highway 17, its western border, U. S. #1, and its northern border approximately 12.3 miles north of the center of Folkston.

This area was chosen because of its proximity to the known heavy mineral deposit just north of Folkston.

The public, unpaved roads of the defined area were logged using the same system configuration as was used during the airborne traverses. Many private roads could probably be logged if time had permitted the gaining of permission from the individuals and corporations involved. If these roads could have been properly mapped (high altitude photographic techniques) and proper permission obtained, the added data could have significantly increased the statistical reliability of the results. No paved roads were used in the compilation of the data since these roads generally have several feet of material of varying origin serving as a roadbed and (1) this material will shield the underlying material from the detector and (2) the material, if it is from some locale other than the immediate vicinity, probably will contain different amounts of radioactive elements than the native material. Even unpaved roads are suspect if foreign materials were used in their surfacing, such as gravel and/or shells.

At the junctures of most of the unpaved roads and the aerial traverses, the readings of both logs were compared. These 23 pairs of values, each representing reasonably the same geographic locations have a correlation coefficient of .75. The calculations of this report were done using the Univac 1108.

Much of the area is totally inaccessible by truck even if all private roads could be used. In areas such as these the use of a helicopter is necessary if holes in the data are to be filled. These data gaps are present in both the airborne-ground correlation described above, and in the ground sampling described below.

4) In sampling the area both hand and power augers were used. The sample locations were chosen so that some coincided with high radiation anomalies and others with low radiation readings. The hand auger samples were taken to a depth of 3 feet and the power auger, to 10 feet or clay, whichever came first. It is generally accepted that the radiation, as measured, represents only the top 1 foot or less of the soil, although the half value thicknesses of the various soil types is not known.

The samples were analyzed in the laboratory for heavy mineral (H.M.) content (heavy mineral = mineral with specific gravity over 2.96) and in some cases TiO_2 content. The correlation coefficient between truckborne radiation and percent H. M. is .14, and between airborne radiation and percent H. M. is .08.

Correlation between these parameters is essentially non-existent. This lack of correlation can be explained by several possibilities.

1) Poor control of aircraft because of varying wind speed and direction and aircraft speed. This could result in mislocating a sample by several hundred feet.

2) Operations were flown during the mornings when generally higher radon concentrations could produce erroneous readings.

3) Ground sampling had to be done in soil off the roadbed. The truckborne instrument was reacting to radiation from the roadbed.

4) The correlation between radioactive minerals and heavy minerals may not be sufficiently close to warrant its use as an exploratory tool.

The first 3 above are statements of conditions. The fourth is a possibility which can be, and should be, studied further. The most likely answer to the fourth possibility is that a significant correlation between heavy minerals and radioactive minerals does exist locally. To base an exploration program on this correlation, the investigation should first establish what correlation, if any, exists in the area of interest. From this, the usefulness of radiation surveys in the area could be established.

On several occasions, the multi-channel analyzer was available for field use. Several areas, both of high and low radioactivity levels, were checked for the entire spectrum from .1 to 1.9 MEV. No output device was available except a visual, on the spot, CRT, thus no data could be returned to the office.

The results of these analyses appeared to confirm the presence of thorium and uranium, but the lighting conditions and small CRT lessened the reliability of these observations. The chief use of the multi-channel analyzer in this study was for calibration of the single-channel analyzer. The multi-channel analyzer was on loan and was available only when not in use by its owner. A multi-channel system has since been acquired.

The isorad map of the area (plate I) was done as a courtesy by the California Computer Products Corporation (Calcomp). The Calcomp contouring program is one of several available commercially. As in all contouring, whether by hand or machine, the contours are not precise, but reflect one man's (in this case, the Calcomp programmer's) opinion.

Conclusion

Because of the many significant variables encountered in this study, (e.g. aircraft speed, navigational control and low counting rates of the higher energy gamma rays) future studies utilizing airborne pulse height analysis are not recommended. The very low counting rates of the higher energy gamma rays necessary for quantitative or semi-quantitative analysis requires a stable platform for a 1,000 to 10,000 second counting period. Currently commercial radiation surveys measure gross gamma radiation rather than pulse height analysis. These commercial surveys are adequate for reconnaissance work if they record and utilize such parameters as aircraft speed and elevation above ground surface and have accurate ground control. Follow up work using a pulse height analyzer from a stable platform such as a truck or helicopter is recommended.

As is shown by the work under theoretical considerations, any above-surface work, whether truck or airborne, will give positive results only when a radioactive "halo" is present at the surface. For this reason an airborne survey should be recognized as an indicator of these "halos" and nothing more. An area with no surface radiation anomaly does not mean the absence of radioactive materials below the surfaces. Proper techniques must include a drilling and well logging program.

Theoretical Considerations

The effect of elevation, depth of body, and half-value thicknesses of air and soil on the intensity of radiation at the detecting crystal can be seen in the following relationship:

$$I_d = \frac{I_o}{2^{(D/\lambda_s + E/\lambda_a)}} \qquad (1)$$

Where, I_d = Intensity of radiation at detecting crystal

I_o = Intensity of radiation at its source

D = Depth of body

E = Elevation (above ground) of detecting crystal

λ_a = Half value thickness of air

λ_s = Half value thickness of soil

This equation represents the radiation received at the crystal from a point source directly below the crystal.

If it is assumed that the half value thickness of the soil is between 2 and 3 inches, the depth of burial of the body is critical. At a depth of 1 foot and an assumed half value thickness (λ) of 3 inches, only 1 part in 16 of the original radiation reaches the surface of the ground. If the half value thickness is decreased to 2 inches, only 1 part in 64 reaches the ground surface. For a depth of 5 feet and a 3 inch λ, only 1 part in 1,050,000 reaches the surface. Figure 1 graphically illustrates this relationship between the radiation received at the ground surface and the radiation emanating from the upper surface of the buried radioactive body. This graph assumes only the vertical contribution of radiation.

For air the half value thickness is on the order of 300 feet. For altitudes of 300-600 feet this results in the loss of 50% to 75% of the radiation which reaches the ground surface. The actual half value thickness of air will vary with changes in humidity and barometric pressure.

The effect of bed thickness on the level of radiation emanating from the upper surface of the body is shown in Figure 2. The following equation (2) relates the intensity of radiation (I) received at a point on the surface of a tabular radioactive body of thickness "T", half-value thickness, λ, and activity, A. Activity may be defined as the number of gamma ray emmissions per unit volume per unit time.

$$I = 2\pi A \int_0^T \int_0^R \frac{r\ dr\ dt}{2^{\left(\sqrt{r^2 + t^2}/\lambda\right)}(r^2 + t^2)} \qquad (2)$$

In this equation, "r" represents the horizontal distance of a contributing point source of radiation from the receiving point.

Figure 2 shows the response of the system to bed thickness. From Figure 2 it is seen that over 99% of the radiation expected from a bed of infinite thickness is obtained from a bed of 11 inches with a λ of 2 inches and a bed of 14+ inches with a λ of 3 inches. The integration was done by computer using a value of .1 inch for dr and dt.

Figure 3 shows the response at the ground surface of a body of activity (A) buried by an inert overburden of (d) inches. The radioactive body is infinitely thick.

Figure 4 shows the response at ground surface if the overburden has background activity (B) and the radioactive body has 6, 10, and 100 times that of the overburden.

The effect of the speed and time constant is critical for interpretative purposes. The "speed" used here is ground speed and it varies when either the engine speed is changed or the wind velocity or direction changes. Under common conditions the ground speed may vary from 60 to 120 mph which, in conjunction with a 2 second time constant, can effectively displace an anomaly from 176 feet (at 60 mph) to 352 feet (at 120 mph). At a 10 second time constant, which results in more stable readings, the displacements would range from 880 to 1760 feet.

In addition to the relative displacements caused by various speeds, attempts to adjust the engine speed result in torque changes in the propeller which in turn tend to change the course of the aircraft. This problem tends to compound the problem of crosswind effects.

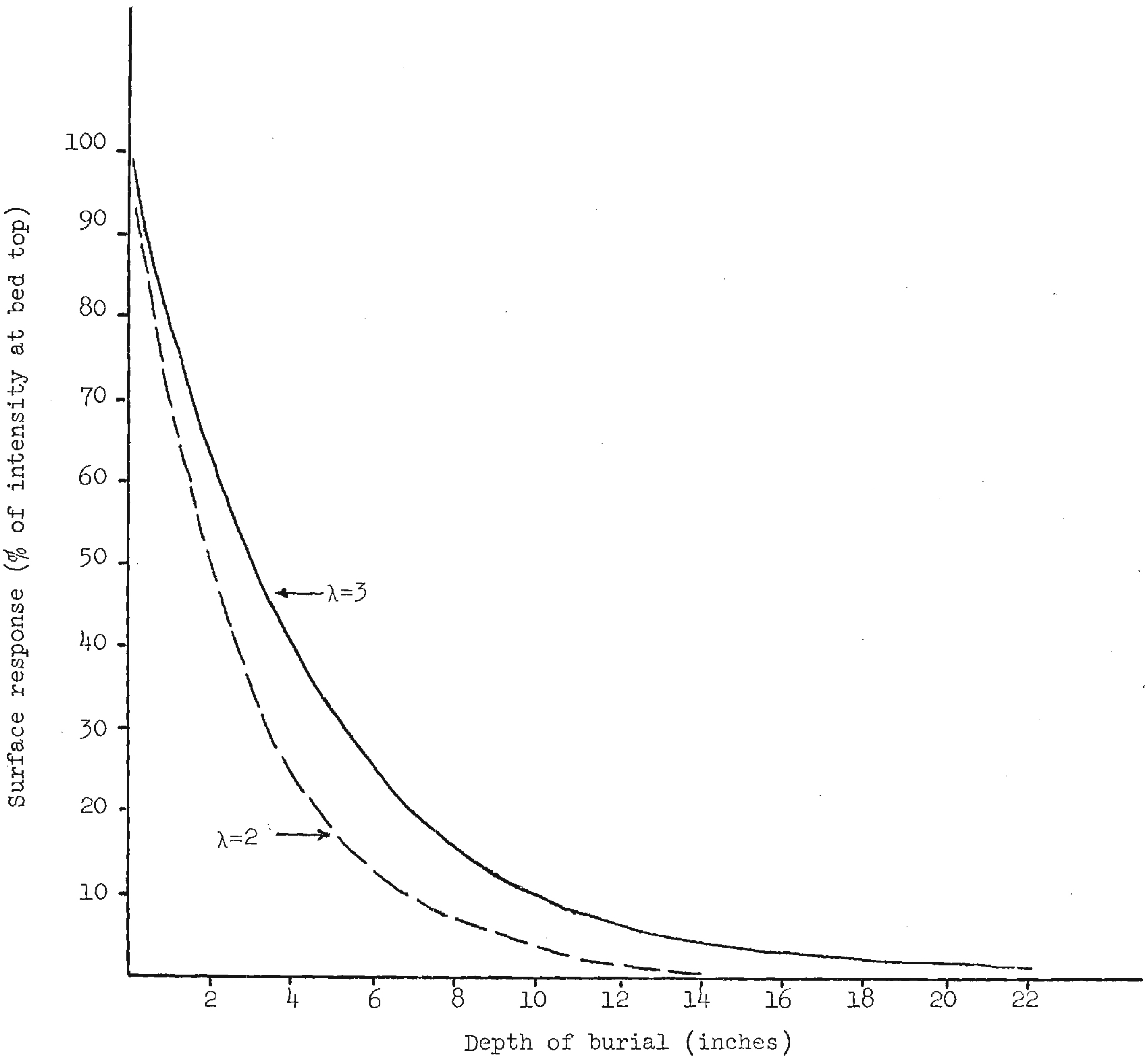

Fig. 1 Attenuation of radiation passing through "d" inches of material with $\lambda = 2, 3$

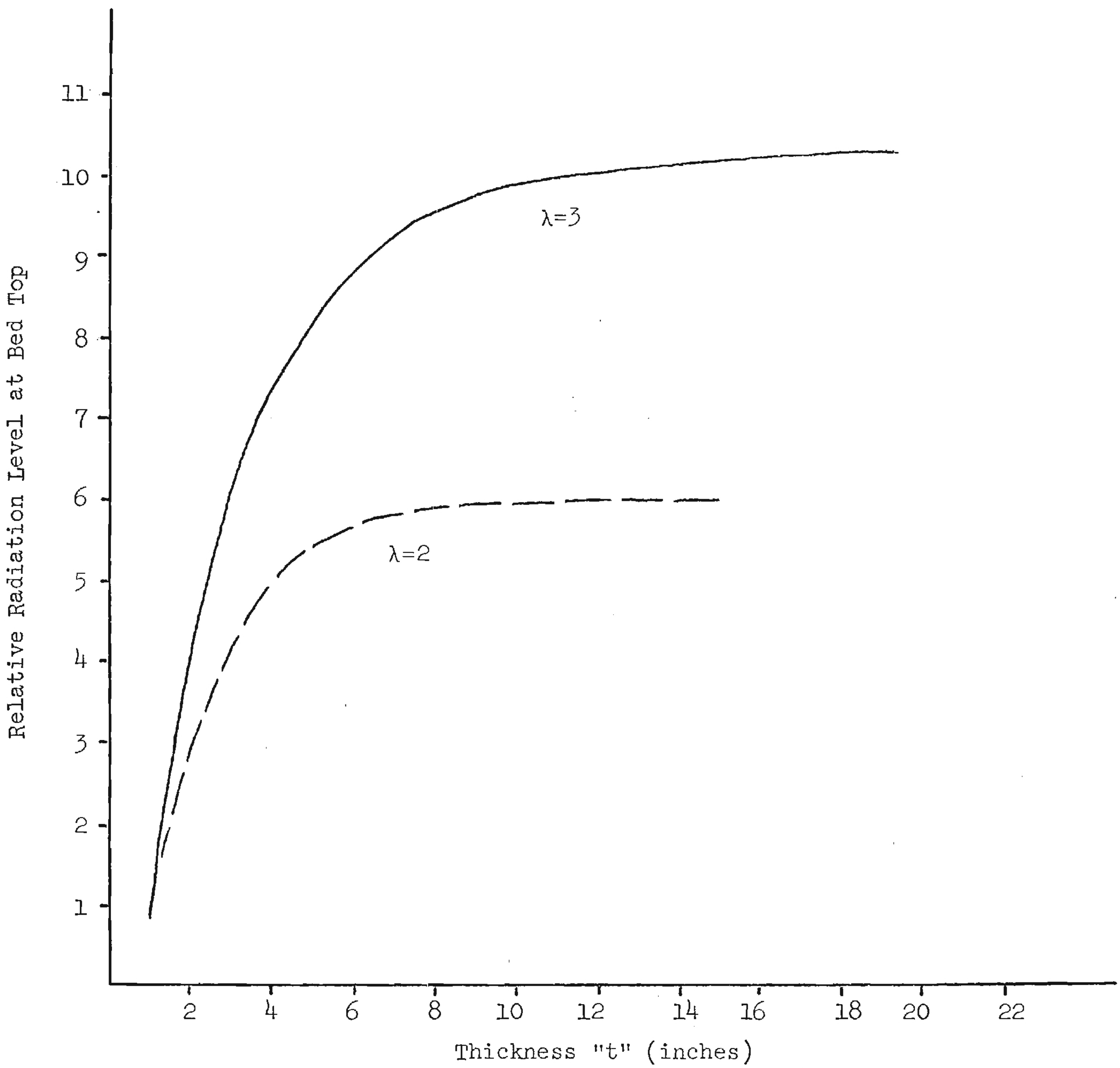

Fig. 2 Radiation expected at top surface of radioactive bed of thickness "t".

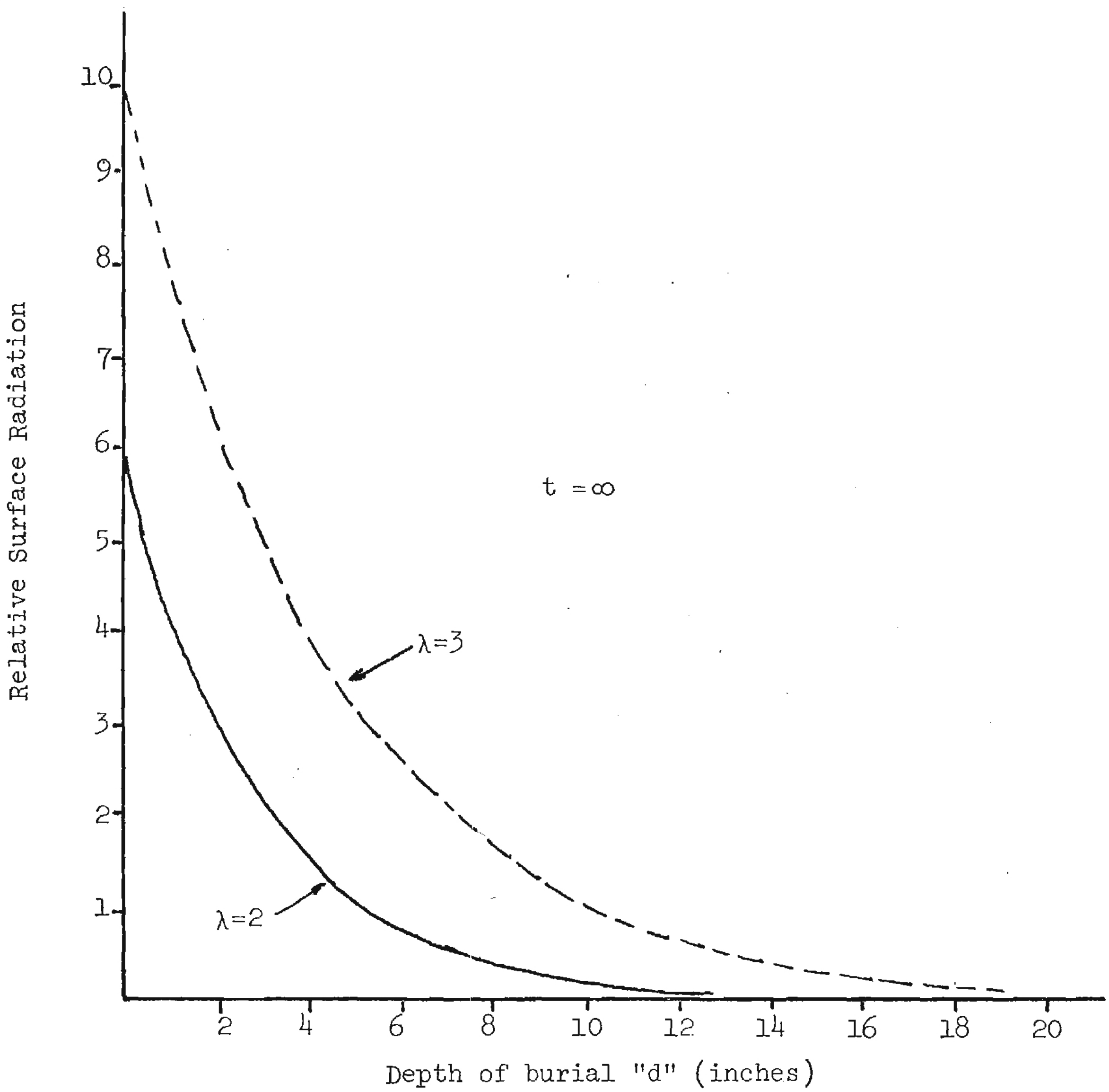

Fig. 3 Surface radiation from body of Activity (A) buried beneath "d" inches of inert overburden

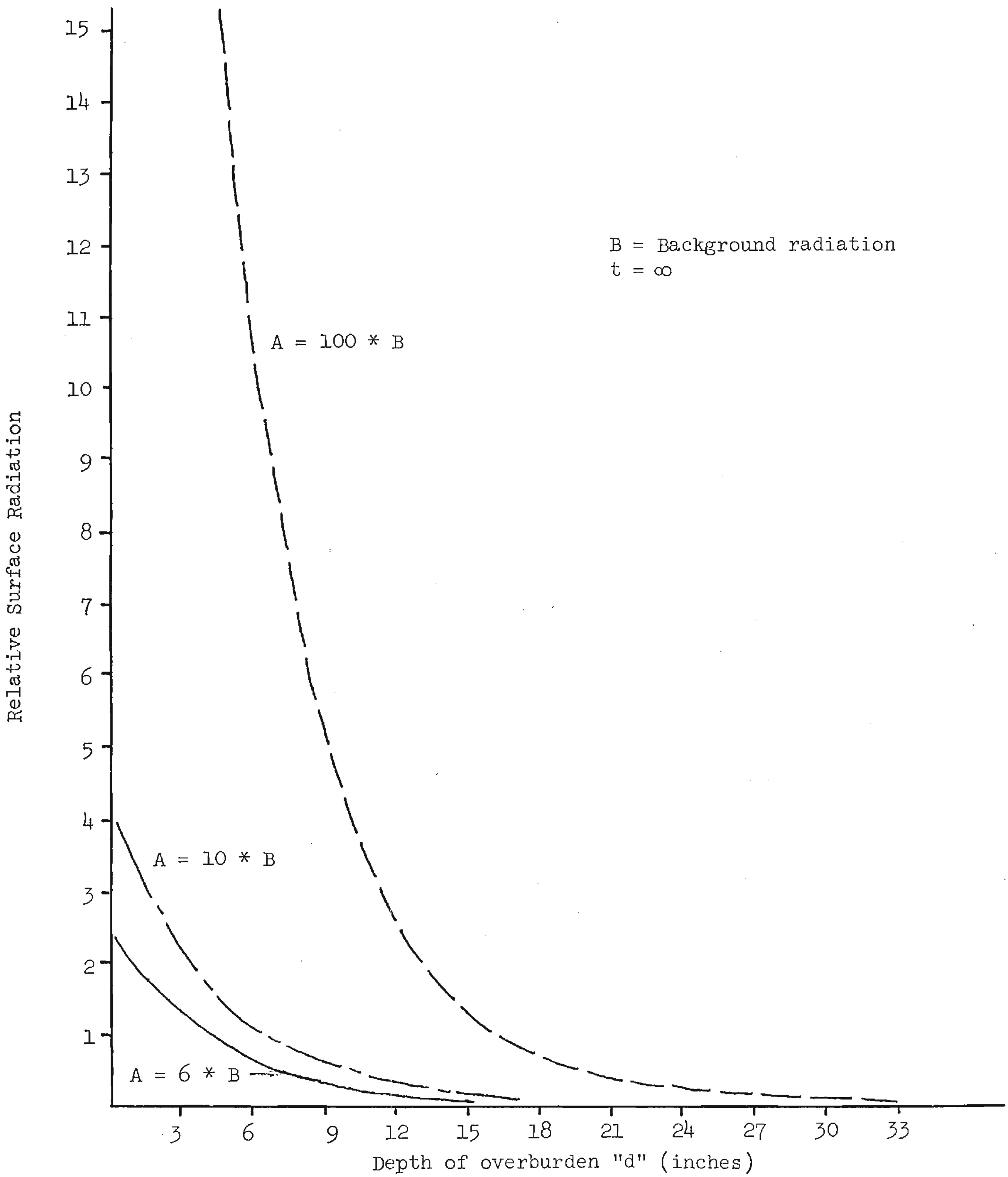

Fig. 4 Surface radiation from body of activity (A) buried beneath "d" inches of overburden of Activity (B)